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GB 0758009
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C7A

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(54) Wear-resistant stainless steel

(57) A high chromium stainless steel especially suited for use as wear (galling) resisting components, for example, valve parts. A typical alloy generally contains chromium, nickel, silicon, carbon, an effective cobalt content and the balance iron plus normal impurities. The alloy may be produced in the form of castings, P/M products, hardfacing and welding materials and wrought mill products.

The compositional range of the alloys is as follows:—

	Wt %
Cr	10—40
Ni	5—15
Ni+M	20 maximum
Si	3—7
C + B	0.25—3.5
N	0.2 maximum
Co	5—30
One or more {Mo, W, V, Ta, Nb, Ti, Cr, Zr, Hf}	10—40
Fe + Impurities	Balance

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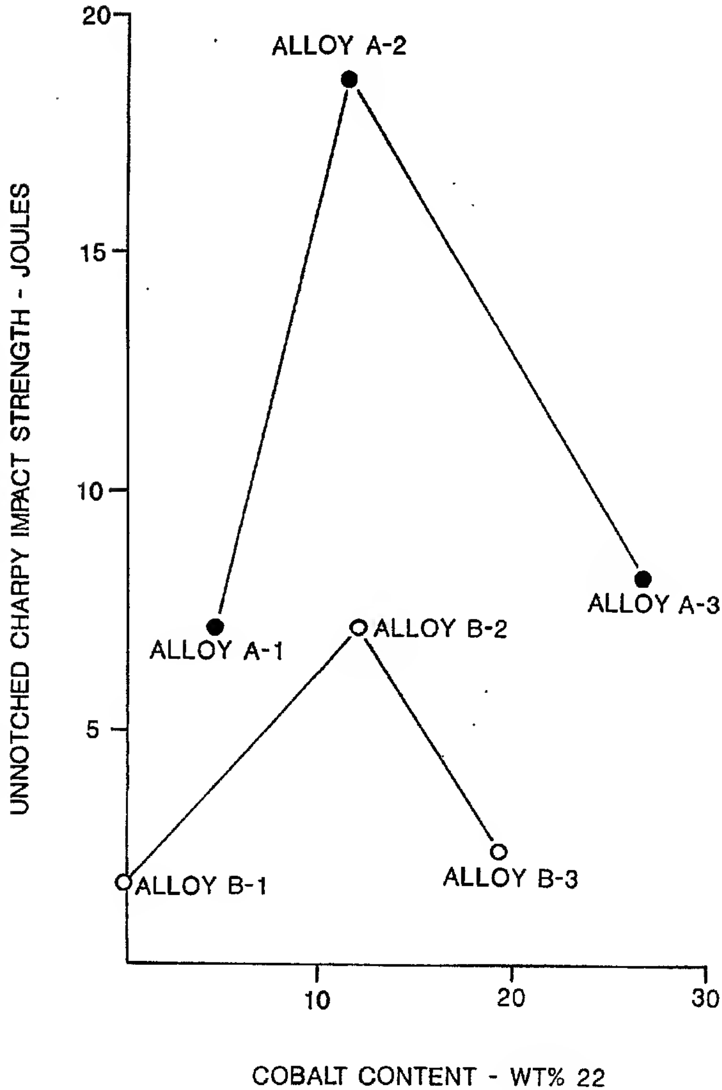
UNNOTCHED CHARPY IMPACT STRENGTH
AS A FUNCTION OF COBALT CONTENT



SPECIFICATION

Wear-resistant stainless steel

This invention reletes to iron-bese alloys and, more particularly to a high chromium stainless steel suitable for severe service wear-resistant applications, such es valve components.

Stainless steel has been in the state of constant development and improvement since its invention as an Fe-Cr-Ni corrosion resistant steel. There are hundreds of verieties of stainless staals. Many have been designed for specific uses. The prior art is replete with modificetions in steel compositions to provide desired specific propartias as required.

There is a critical need for a low cost alloy resistant to corrosion and mechanical wear as now provided by cobalt-base alloys. A well known alloy of this class is marketad as STELLITE (R.T.M.) alloy No. 6 containing typically 28% chromium, 4.5% tungsten, 1.2% carbon, belence cobelt. Beceuse of the low cost and availability of iron, some iron base elloys have been proposed for weer epplicetions. For example U.S. Patent 2,635,044 discloses the basic 18—8 stainless steel with additions of molybdenum, beryllium and silicon as a hardenable stainless steel resistant to galling and erosion-corrosion when heat traatad.

As used herein, ell compositions are given in percent by weight.

U.S. Patent 1,790,177 discloses a wear reeistant steel elloy auitable for use as drilling tools and welding rods. This steel contains only chromium, nickel, silicon and carbon as the essential elements with chromium 25 to 35% as tha principal feature. U.S. Patent 2,750,283 discloses the addition of boron to enhance the hot rolling characteristics of neerly every known chromium iron alloy with or without nickel, carbon, silicon, manganese, molybdenum, tungsten, cobalt or other optional elements. U.S. Patent 4,002,510 discloses the addition of silicon to 18—8 stainless steels to promote the formation of delta ferrite, thus anhancing resistance to stress corrosion cracking.

U.S. Patent 3,912,503 and 4,039,356 relate to e modified 18—8 steinless steel with critical contents of manganese and silicon. Known also in the art is an analogous commercial steel undar ARMCO Inc.'s trade mark NITRONIC 60 containing typically 0.10 max. carbon 8 manganese, 4 silicon, 17 chromium, 8.5 nickel and 0.13 nitrogen. Data ehow these steals have good wear propertles, especially in galling tests.

Metal wear in industrial and consumer mechanical operations continues to be an expanelve and, at times, hazardous problem. Conditions of wear environment era eo diversa that there can be no optimum or perfect weer resistant alloy to solve ell probleme. Furthermore, cost and avallebility of elamants to produce certain wear-resistant alloys become an important consideration. The art is constently searching for new and improved alloys to satisfy these needs.

For example, valve components subjected in service to chemically aggressive media ara constructed either from the stainless steels or high nickel alloys. Typically the stainless 304 is selected by the food processing industry and for other systems which involve mild corrodants, 316 is well used by the chemical processing industry, and the high nickel alloys are selected when severely aggressive media are present.

A major drawback of the 300 type stainless steels and the high nickel alloys, however is their tendency to gall (i.e. suffer from severe surface damage) when they are subjected to relative motion under the high loads inherent in valve operation. Of particular concern, in this respect are the valve seat faces, which must retain their integrity for sealing purposes.

Generally speaking, the 300 series steels are the basic corrosion rasistant stainless steels. As a means to reduce the use of nickel, the 200 series stainless steels were developad wherein manganese and nitrogen were substituted for a portion of the nickel. These 200 series steels were found to have improved mechanical strengths over the 300 series steels for some uses. To improve the galling resistence of these alloys, higher silicon contents were added resulting in the alloys of NITRONIC 60 type. NITRONIC 60 has improved galling resistance when compared to the 200 and 300 series steels.

Experiments have shown NITRONIC 60 to have a high degree of resistance to galling when the alloy is coupled to itself. However, there is only limited resistance to galling when coupled with other counterfaca materials, in perticular the 300 series steels and high nickel alloys. Thus there is a limitation in the use of these alloys in the art.

Furthermore, in the generel production of nitrogen containing alloys, experience has shown that nitrogen content is difficult to control. Nitrogen tends to promote ges problems during welding. Manganese appears to be the source of seriee deterioration of certein furnace lining materials.

The present invention seeks to provide an alloy that has a higher degrea of wear resistance than is now available and that is more wear resistant under a variety of wear conditions.

Table 1 presents the ranges of composition that define various embodiments of tha alloy of this invention. The broad range in Table 1 defines the scope wherein some advantage of the invention may be obtained under certain circumstances. The preferred range in Table 1 defines the scope wharain a highar degree of advantages may be obtained. Data show that meny properties are improved with compositions within this range. The more preferred range in Table 1 defines the scope wherein a more desirable combination of engineering proparties are obtained.

The typicel elloy defined in Table 1 is the optimum composition of one embodiment of the

invention. The typical alloy has an effective working scope essentially as defined in the Typical range as shown in Teble 1.

TABLE 1
Alloy of this Invention
Composition, in Weight Percent

Element	Broad	Preferred	More Preferred	Typicel	Typical Range
Cr	10—40	15—40	25—40	30	28.5—31.5
Ni	5—15	7—13	7—13	10	9—11
Ni + Mn	20 max	15 max	15 mex	ebout 10	—
Si	3—7	3.5—6	4—5.5	4.7	4.4—5.2
C	—	—	—	1	.85—1.15
C + B	.25—3.5	.75—3.0	.75—2.5	about 1	—
N_2	.2 mex	.15 max	0.10 max	—	—
Fe plus Impurities	Bal	Bal	Bal	Bal	Bal
Co	5—30	5—20	9—15	12	11—13
Carbida/ boride formers*	10—40	15—40	25—40	about 30	about 30

*Molybdenum, tungsten, vanadium, tantalum, columbium, titanium, chromium, zirconium end hefnium

Chromium is present in the elloy of this invantion to provida corrosion resistance and to promota the formation of chromium cerbides, chromium borides end the like. Less then 10% chromium will not provide sufficient corrosion resistance while over 40% chromium content will tend to reduce ductility of the alloy.

Nickel must be present to promote an austenitic structure in the alloy. At least 5% nickal is required to be effectiva; but over 15% does not provide additional benefits. Test results show that with nickel et only 5.12% there is a high degree of galling demege with the alloy coupled with a high nickal alloy. With nickel et 14.11% there is also poor galling resistance with a high nickel alloy and when tha 14.11% nickel alloy is coupled with itself.

Silicon must be present in the alloy to enhance the anti-galling characteristics of the alloy. Less than 3% is not sufficient while over 7% will embrittle the alloy.

The alloy of this invention is enhenced with the formation of carbidas and boridas of a group of elements including molybdenum, tungsten, venadium, tantalum, columbium, titanium, chromium, zirconium, hafnium and others known in the art. Carbides and borides of iron, of course mey be formed. To obtain these cerbides and borides in the alloy in effective emounts, carbon and boron must be present totaling not less than .25%. Over 3.5% total carbon and boron will tend to reduce the ductility of the alloy. The total content of carbide or boride formers (other than iron) listed ebove must be present not less than 10% to be effective; but ovar 40% will tend to reduce ductility end further edd to costs.

It is understood that the carbides end borides may be in the form of complax structures with three or more elements, for example, a chromium iron carbide. Of course at least e portion of the cerbide-boride former elements may be found in the matrix.

Nitrogen may be beneficial in the alloy of this invention for some epplications and may be present in an effective amount not more than .2% to avoid the formetion of excessive nitrides and avoid problams ralated to gas in weldments.

Cobalt is aspecially critical in the composition of the alloy. Subsequent data will show a controlled content of cobalt provides assential features of the alloy, and in particular, impact strength. Cobalt content must be at least 5% to provide an effective increased impact strength. Over about 30% cobalt the baneficial effects of cobalt ere lost end no additional improvement is provided in view of the additional costs. Actual test results show the optimum cobalt content is about 12%. Thus, a preferred renge of cobelt et 5 to 20% is suggested for best advantages of the invention.

In a series of tests the criticality of cobalt was tested in two iron base alloys. Alloy A is essentielly alloy 57B1 in Teble 2 except for cobelt. Alloy B contained 20.37 chromium, 9.83 nickel, 4.74 silicon,

2.2 carbon and 7.93% vanadium. Cobalt edditions were mede in the basic Alloys A and B. The resulting alloys were tested for impact strength. Tests were performed on the standard Charpy impact testing unit and values were obtained in joules from unnotched specimens. Data are presented in Table 3 and graphically in the attached figure.

The data and the figure claerly show that a controlled content of cobalt dramatically affects impact strengths. The data show that about 12% is the optimum cobalt content. Tha affact of cobalt continuas to be beneficiel up to ebout 30% cobalt content for Alloy A and 20% cobalt content for Alloy B.

The data also show that basic Alloy A generally has higher impact strength; however, the influence of cobalt in basic Alloy B is similar.

Considering all of the material combinations tested data as shown in Table 4 show when cobalt is present at only 4.86% (Alloy A—1), general resistance to galling is less than the alloy containing 11.95% (Alloy A—2). Howaver increased cobalt content to 26.92% (Alloy A—3) results in little improvement in resistance to galling. As a means to make direct comparison with known prior art alloys, Table 4 also presents data for STELLITE alloy 6, NITRONIC 60 and HASTELLOY alloy C—276 the well known nickal base alloy. The galling test procedure will be described hereinafter.

These waar data show the alloy of this invention to ba comparable to or better than typical commarcielly aveilable alloys.

In view of these data, it is suggested the maximum cobalt content should be 30% and, preferably at 20% in view of cobalt costs.

Manganese is not essential in the alloy of this invention but may be prasent in the alloy together with nickel in a total amount not exceeding 20%.

TABLE 2
Example Alloys of this Invantion in wt.%

	Alloy 6781	Alloy 6781—W
Cr	29.54	29.07
Ni	9.72	11.08
Ni + Mn	—	11.58
Si	4.73	4.23
C	1.07	1.07
N_2	.06	.01
Fe plus impurities	Bal	Bal
Co	11.95	10.82

TABLE 3
Effects of Cobalt

Basic Alloy A	Cobalt Content	Unnotched Impact Strength, Joules	ft. lbf.
A—1	4.86%	7.1	5.2
A—2	11.95%	18.6	13.7
A—3	26.92%	8.1	6.0
Basic Alloy B			
B—1	0	1.7	1.3
B—2	12.33	7.1	5.2
B—3	19.37	2.4	1.8

TABLE 4
Galling Test Data
(Micrometers (μm) can be Converted to Microinches by Multiplying Micrometers by 39.4)

TEST COUPLE	DEGREE OF DAMAGE* — μm		
	(3000 lb.) 1360.8 kg	(6000 lb.) 2721.6 kg	(9000 lb.) 4082.3 kg
STELLITE alloy No. 6 v. STELLITE alloy No. 6	1.25	2.50	1.88
STELLITE alloy No. 6 v. 304 Stainless Steel	45.63	40.00	52.00
STELLITE alloy No. 6 v. 316 Stainless Steel	23.50	48.13	58.13
STELLITE alloy No. 6 v. HASTELLOY alloy C—276	21.88	30.00	23.13
STELLITE alloy No. 6 v. 410 Stainless Steel	25.63	28.13	55.00
NITRONIC 60 v. NITRONIC 60	2.50	120.00	111.25
NITRONIC 60 v. 304 Stainless Steel	40.63	111.25	85.63
NITRONIC 60 v. 316 Stainless Steel	38.13	97.50	118.75
NITRONIC 60 v. HASTELLOY alloy C—276	3.25	53.75	115.00
NITRONIC 60 v. STELLITE alloy No. 6	2.50	1.50	3.13
Alloy A—1 v. Alloy A—1	1.00	0.63	0.75
Alloy A—1 v. 304 Stainless Steel	5.38	17.00	28.13
Alloy A—1 v. 316 Stainless Steel	52.50	46.25	55.00
Alloy A—1 v. HASTELLOY alloy C—276	13.00	15.50	10.38
Alloy A—1 v. STELLITE alloy No. 6	0.63	1.25	1.25

TABLE 4
(Micrometers (μm) can be Converted to Microinches by Multiplying Micrometers by 39.4)

TEST COUPLE	DEGREE OF DAMAGE* — μm		
	(3000 lb.) 1360.8 kg	(6000 lb.) 2721.6 kg	(9000 lb.) 4082.3 kg
Alloy A—2 v. Alloy A—2	1.25	1.50	1.50
Alloy A—2 v. 304 Stainless Steel	0.88	2.88	3.63
Alloy A—2 v. 316 Stainless Steel	11.00	22.88	35.63
Alloy A—2 v. HASTELLOY alloy C—276	1.75	0.63	2.63
Alloy A—2 v. 410 Stainless Steel	2.50	3.00	7.25
Alloy A—2 v. STELLITE alloy No. 6	1.13	1.13	1.13
Alloy A—3 v. Alloy A—3	0.88	1.13	0.88
Alloy A—3 v. 304 Stainless Steel	1.38	1.25	2.88
Alloy A—3 v. 316 Stainless Steel	4.25	23.88	42.38
Alloy A—3 v. HASTELLOY alloy C—276	2.13	0.88	2.25
Alloy A—3 v. STELLITE alloy No. 6	2.13	1.75	2.13

TABLE 5
Cherpy Impact Date

Alloy	Impact Strength — Joules (ft. lbf.) Notched	Unnotched
6781—W	5.4 (4.0)	88.8 (65.5)

EXAMPLES

A series of experimental elloys was prepared for testing.

The alloy examples for testing were induction melted and aspiretion cast into glass tubes yielding 4.8 mm (.188 inch) diemeter weld rods. Depositions of the weld rods were made by ges tungsten arc melting. The deposits were feshioned into test specimens.

Alloy 6781—W of this Invention wes prepared in the form of wrought product. Table 2 shows the analysis of the alloy. The alloy was vecuum induction melted, then electroslag remelted (ESR). The ESR bars were forged at about 1177°C (2150°F) then hot rolled at the same temperature into plate and finally to about 1.59 mm (1/16 inch) thick sheet for testing. Galling test data show the alloy of this invention, in wrought form, to have outstending anti-galling properties similar to the properties of the elloy in the form of hard-facing deposits.

The wrought alloy wes impact tested by the standerd test method wall known in the art. Data are presented in Table 5.

Powdar products may also be produced from the alloy of this invention. A composite product mey be formed by the mixture of the elloy of this Invention with hard particles such as tungsten carbide, titanium diboride and the like. The mixture is then further processed into e useful shapa. In addition, components of the mixture may be edded separately to a welding torch end the end product is e composite deposit.

The galling test used to generate the data in Table 4 involved:

a. the twisting beck and forth (ten times through 2.1 rad [120°] erc) of a cylindrical pin (of diemeter 15.9 mm) (.625 inch) against e counterface block under load.

b. study of the test faces (which were initially in surface ground condition) by profilometry to determine the degree of damage incurred during eliding.

Tests were performed for aach tast couple at three loads; 1360.8 kg (3000 lb), 2721.6 kg (6000 lb) end 4082.3 kg (9000 lb). The pins ware twisted manuelly by means of a wrench and the load transmitted by meens of e ball bearing. The neck portion of the pins was designed to accommodate both the wrench and bell bearing.

Since metallic faces, subjected to sliding under high loads, tend to have irregular profiles, often featuring one or two deep grooves, it wes deemed appropriate to meesure degree of damage in terms of the change in maximum peak to valley amplitude (of the profile) rather than the change in average roughness (which would tend to mask the presence of any badly dameged regions).

In visual terms, the cylindrical pin and the block appear to suffer the same degree of damage in a given tast. Only the blocks were used in the quentitative determination of damege, therefore, since they are more amenable to profilometry, allowing travel of the stylus to and beyond the circumference of the scar. For accuracy the stylus was pessed twice over eech scer (one pess elong tha diameter parallel to the sides of the block; the other along the diameter perpendiculer to it). Appreciable overlap of the edjacent unworn surface regions was affected to enable calculation of the initiel peek to valley emplitude.

By considering each radius as a distinct region of the scar, four values of finel peek to valley amplitude were measured per scar. The average of these four velues was used to determine the degree of demage incurred, subtracting the average of four values of initiel peak to velley emplitude.

The galling test procedure used to obtain galling evaluations described ebove was developed end modified from known test methods to provide more severe and more meaningful test results. Thus, the test date reported herein do not necessarily correspond directly with published data obtained by other test methods.

Unless otherwise stated, ell galling tests reported herein were made under identical test conditions and the resulting test data are, therefore, valid in meking direct comparisons among the various alloys tested herein.

CLAIMS

1. An alloy consisting of, in weight percent, 10 to 40 chromium, 5 to 15 nickel, 20 maximum nickel plus manganese, 3 to 7 silicon, 0.25 to 3.5 cerbon plus boron, 0.2 maximum nitrogen, 10 to 40 one or more of molybdenum, tungsten, vanadium, tentalum, columbium, titanium, chromium, zirconium and hafnium, 5 to 30 cobalt and the balance iron plus impurities.

2. The alloy of claim 1 containing 15 to 40 chromium, 7 to 13 nickel, 15 maximum nickel plus manganese, 3.5 to 8 silicon, 0.75 to 3.0 carbon plus boron, 0.15 maximum nitrogen, 5 to 20 cobalt, 15

to 40 one or more of molybdenum, tungsten, vanadium, tantalum, columbium, titanium, chromium, zirconium and hafnium.

3. The alloy of claim 1 containing 25 to 40 chromium, 7 to 13 nickel, 15 maximum nickel plus manganese, 4 to 5.5 silicon, 0.75 to 2.5 carbon plus boron, 0.10 maximum nitrogen, 9 to 15 cobalt, and 25 to 40 one or more of molybdenum, tungsten, vanadium, tantalum, columbium, titanium, chromium, zirconium and hafnium.

4. The alloy of claim 1 containing 30 chromium, 10 nickel, 4.7 silicon, 1 carbon, 12 cobalt.

5. The alloy of claim 1 containing 28.5 to 31.5 chromium, 9 to 11 nickel, 4.4 to 5.2 silicon, 0.85 to 1.15 carbon, 11 to 13 cobalt.

6. The alloy of any one of claims 1 to 5 wherein said cobalt is present in an effective amount to provide combined good impact strength and good wear, especially galling, resistance.

7. The alloy of any one of claims 1 to 5, having a high degree of wear, especially galling, resistance under a variety of conditions.

8. The alloy of any one of the preceding claims in the form of a casting or a wrought product or hardfacing material or as a sintered powder metallurgy product.

9. The alloy of any one of claims 1 to 7 as a component of a composite material wherein said alloy is the matrix with dispersions of hard particles, for example, tungsten carbide or titanium diboride.

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